2.4 mm Diameter Coaxial Power Standard at NIST*

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1. Abstract

A microcalorimeter and bolometric transfer standard are used as a national standard for microwave power from 50 MHz to 50 GHz. The microcalorimeter is used to determine the efficiency of the bolometric transfer standards and is similar to an existing Type N coaxial microcalorimeter at NIST. The transfer standards are dc substitution power detectors that contain a small integrated circuit with two resistors that are closely thermally coupled. The first resistor is insensitive to temperature and has a resistance of approximately 50 Ω. It terminates the coaxial input and dissipates the RF power. The second resistor dissipates DC power. It has a positive temperature coefficient, a resistance of about 1000 Ω and acts as the bolometric element. A power supply maintains this bolometric element at constant resistance. Typical calorimeter data are shown and future plans for development will be briefly discussed.

2. Introduction

The national standards for microwave power in the United States are a set of microcalorimeters and associated bolometer mounts. The calorimeters are the primary standard, while the bolometer mounts are secondary standards. There are two coaxial and five waveguide calorimeters [1] presently in operation. The coaxial calorimeters include a Type N calorimeter [2] in addition to the 2.4 mm calorimeter described here, while the waveguide calorimeters cover frequencies from 18 to 110 GHz.

The bolometer is a temperature-sensitive resistor that is heated by dissipation of DC and RF power. The Type N and waveguide calorimeters use a thermistor bead bolometer. The negative temperature coefficient thermistor terminates the RF transmission line and is also part of a DC feedback circuit that maintains the thermistor at a constant resistance. Thus, turning on the RF power results in a decrease in DC power that can be accurately measured. RF and DC power do not affect the bolometer mount equally, and the calorimeter is needed to determine the bolometer's effective efficiency , $\eta_e = P_{dc,sub} / P_{rf}$, where $P_{dc,sub}$ is the change in DC power when RF is applied and P_{rf} is the net RF power input to the detector. The calorimeter measures η_e by measuring the relative temperature change of the mount with and without RF power.

3. Apparatus

3.1 2.4 mm coaxial bolometer mount

The RF input section of the 2.4 mm coaxial bolometer mount uses a coplanar waveguide on a sapphire substrate. The transition from coaxial to coplanar utilizes a bellows on the center conductor. Outer conductor contact is through the housing that holds the sapphire substrate. The coplanar waveguide connects to a smaller integrated circuit mounted on the sapphire substrate where two thin-film resistors are located. The housing and sapphire substrate were adapted from a commercially available mount, while the smaller integrated circuit was manufactured specifically for this detector. The bolometer mount is shown in Figure 1 along with the calorimeter. Note that in the picture, the mount lies horizontally on the base plate. When in operation, it extends upward from the connector at the top of the central structure.

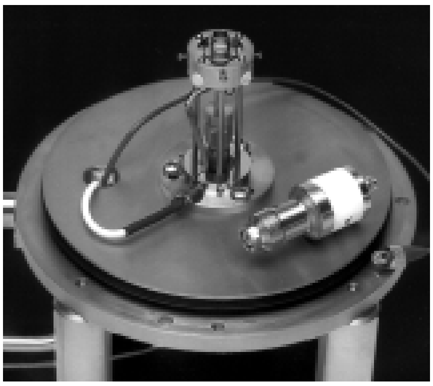

Figure 1 2.4 mm coaxial microcalorimeter and bolometer mount.

The two thin-film resistors on the small integrated circuit are mounted in very close thermal contact. A 50 Ω,TaNi resistor terminates the RF input, and a positive temperature coefficient platinum resistor is connected to a self-balancing DC circuit that is a modification of the circuit used for thermistor bolometers [3]. The circuit adjusts the DC power through the platinum resistor until its resistance matches a reference resistance. The circuit modifications consist of (a) reversing an op-amp input so that the feedback circuit is stable for a positive temperature coefficient resistor and (b) using an external reference resistor. The required external reference resistor varies from 600 to 1400 Ω depending on the particular mount used.

3.2 2.4 mm coaxial microcalorimeter

Figure 2 is a sketch of the entire microcalorimeter. The assembly is illustrated with the cover raised for ease of viewing. When in operation, the microcalorimeter is suspended in a water bath by the hanger that extends from the top of the cover. The water bath is stable to 50 μK [4,5]. The RF input, DC bias, and thermopile leads are brought in through the bottom of the microcalorimeter for easier assembly and disassembly. Their path through the water also brings the conduits to the bath temperature. The entire assembly is gold-plated for protection against corrosion and to reduce the effect of thermal radiation.

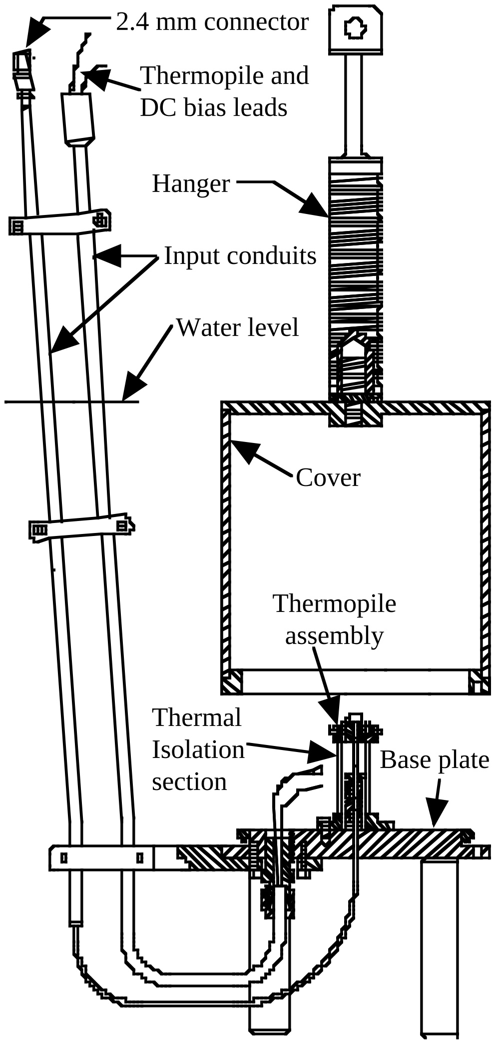

Figure 2 View of the entire microcalorimeter assembly

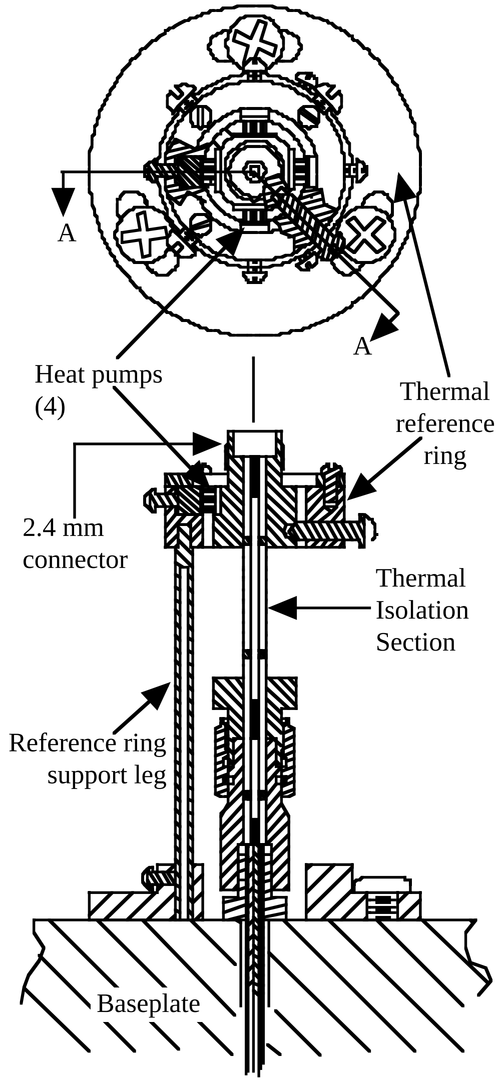

Figure 3 Top and cross-sectional views of the microcalorimeter's thermal isolation and thermopile sections. Not to same scale.

A close-up of the thermal isolation and thermopile portion of the microcalorimeter is shown in Figure 3. The bottom base plate is in thermal contact with the water bath. A 2.4 mm pin connector terminates the microwave input. This connector mates to a coaxial thermal isolation section consisting of a thin-wall (~0.013 mm) outer conductor and solid inner conductor. Both are made of gold-plated beryllium copper. On the top of the thermal isolation section is a 2.4 mm socket connector that mates to the bolometer mount. The thicker section at the top between the connector and the thermal isolation section makes contact with a set of four Peltier-effect heat pumps that are connected electrically in series. These provide a thermopile to measure the temperature rise of the bolometer mount relative to a reference ring located at the same height and larger radius. The reference ring is supported by three stainless steel tubes. Ideally, the reference ring and support legs approximate the thermal characteristics of the dummy transfer standard used in twin-joule microcalorimeter designs [6]. However, because of practical considerations, they match within about a factor of two. This results in a greater sensitivity to changes in bath temperature, which is not a great concern for the bath used in these experiments.

4. Calorimeter Measurements

The thermopile measures the rise in temperature of the attached bolometer mount. With DC bias only, the thermopile voltage, *e*, can be expressed as $e_1 = kP_{dc1}$, where P_{dc1} is the DC bias power and k is a proportionality constant determined by this measurement. With both DC and RF applied to the mount, the thermopile voltage becomes $e_2 = k(P_{dc2} + gP_{rf})$where the factor g ~ 1, represents the difference in the calorimeter's response to RF and DC power. This difference is due to the RF power dissipated in the mount's input section and in the calorimeter's thermal isolation section. An expression for the effective efficiency η_e can be derived from the expressions for e_1 and e_2, and is given by

$$\eta_e = (P_{dc1} - P_{dc2}) / P_{rf} = g \frac{1 - \frac{P_{dc2}}{P_{dc1}}}{\frac{e_2}{e_1} - \frac{P_{dc2}}{P_{dc1}}} \tag{1}$$

For the 2.4 mm calorimeter, the correction factor g was determined using two bolometer mounts that were modified by removing the small integrated circuit and replacing it with an open and short circuit. A complete explanation of this measurement is deferred to a later publication. The other parameters are all directly measured.

The calorimeter is placed in the water bath and the bias voltage and thermopile allowed to reach equilibrium. This generally takes a few hours. Then, a measurement run such as the one shown in Figure 4 is performed. The measurement procedure is computer controlled and begins with a DC-bias-only measurement, which lasts about 9 minutes for the data shown in Figure 4. It then steps through a set of frequencies, and ends by making a final DC-bias-only measurement. The output power of the RF source is controlled by feedback to maintain a constant bias voltage such that the DC substituted power is about 10 mW. A set of data is recorded every 30 seconds and a computer algorithm determines whether the system has reached a new equilibrium. If it has, the RF power is turned off for a few seconds and another set is recorded during this time (the upward spikes in Figure 4b). The program then steps to the next frequency and the RF is turned back on. An individual frequency measurement usually takes 20 to 60 minutes. e_2 and P_{dc2} are measured at the end of each frequency segment, P_{dc1} is measured during the brief "off" period between frequencies, and e_1 is interpolated from the initial and final DC-bias-only measurements. A complete calibration of the mount includes about 500 frequencies and takes 1 to 2 weeks. The effective efficiency determined from the data in Figure 4 and from 26 other files is shown in Figure 5. The uncertainty in the measurement is dominated by the uncertainty in the correction factor g. The expanded uncertainty (k=2) ranges from 0.009 at low frequencies to 0.016 at 50 GHz.

5. Future Work

There are two significant concerns with the present system. The first is that the open and short used to determine the correction factor g did not have an integrated circuit and therefore, no DC bias was applied. We now have a second set of open and shorts with an integrated circuit that will allow us to more closely match the mount's thermal properties. New measurements to evaluate g have begun. A more serious problem is that in addition to the fast time scale changes in the DC power evident in Figure 4b, there is a slow time scale component that can be a few percent of the total signal and has a time constant of over 10 minutes. This effect is strong only when the mount is in the calorimeter, and is believed to be due to insufficient thermal isolation between the thin-film resistors and the rest of the mount. A re-design of the thin-film chip to reduce or eliminate this problem is under consideration.

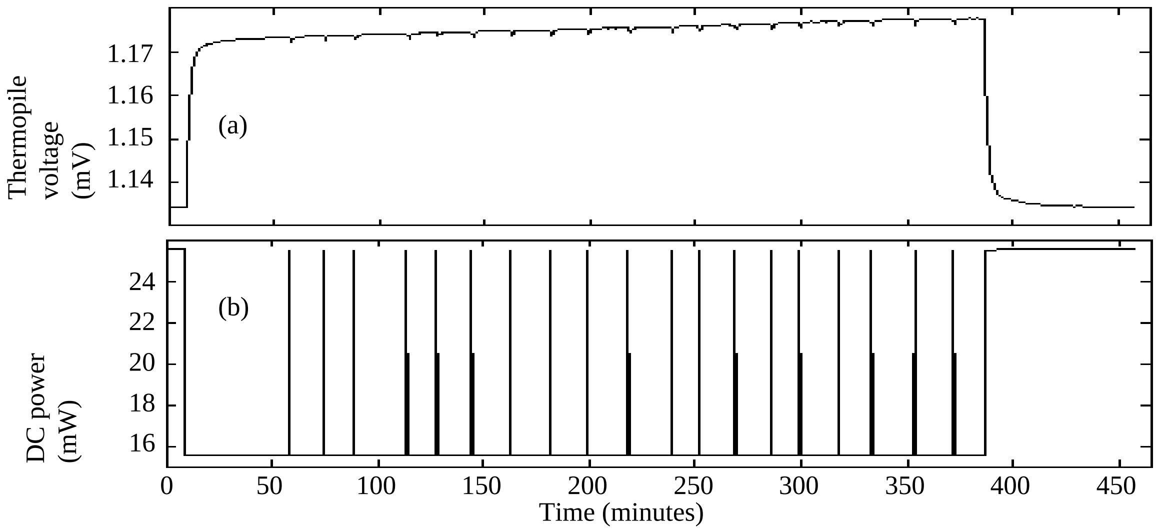

Figure 4 (a) Thermopile voltage (e in equation (1)) and (b) P_{dc}, the DC power in the bolometer resistor recorded during a typical calorimeter measurement.

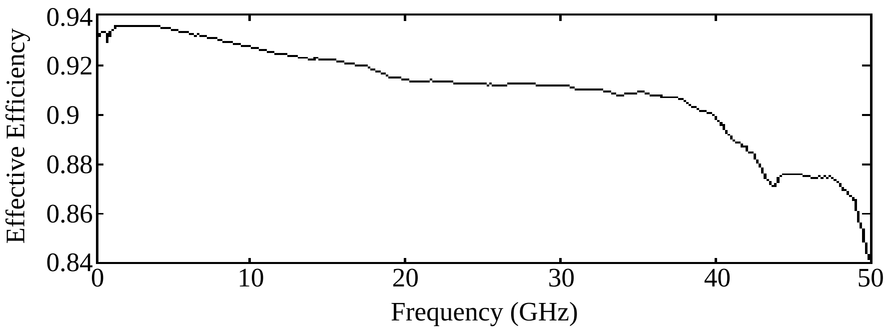

Figure 5 Effective efficiency of 2.4 mm mount determined from data including that in Figure 4.

6. Acknowledgments

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7. References

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